Nuclear Waste Repository, Palo-Duro Basin,
Northern Texas

by

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Abstract

This paper reviews and evaluates the hydrologic criteria presently used to define potential high-level radioactive waste storage within the bedded salt deposits of the Palo-Duro Basin of Northern Texas. Two criteria are presented which are designed to characterize the hydrological performance of a nuclear waste repository within a selected geologic medium. These criteria are: I) Hydrologic analysis must define the local and regional groundwater flow regimes, and determine the effects of repository construction on those systems and II) Analysis of the geologic record and previous hydrological conditions of the selected site must be made for prediction of favorable or unfavorable long-term hydrologic conditions. These criteria are then applied to the proposed repository site within the Palo-Duro Basin for hydrologic evaluation of the site.

Introduction

The harnessing of nuclear fission in the 1950's was a very important, yet problematic technological advancement. Since that time many of the predictions of cheap, abundant nuclear energy have not been realized, and in addition new technological considerations have forced us to make a more cautious evaluation of cheap, abundant nuclear power as a major source of energy. The scientists who originally developed the technologies involved in the nuclear fuel cycle virtually ignored the most basic problem of what to do with the large amounts of radioactive wastes generated by nuclear power plants. Today it should be apparent to all but the most unaware of earth's citizens that as we increase our demand for energy, we must also increase the means by which that energy is produced. Nuclear power, for better, or for worse, will play an ever increasing role in this future energy generation. The need to develop safe, sane disposal technologies is then of utmost importance.

Early in 1976, the U.S. Energy Research and Development Administration established the National Waste Terminal Storage Project. This project's goals were to assess the feasibility of using the deeply buried salt deposits within the Palo-Duro Basin, as well as other geologic media, for high-level radioactive waste disposal. The U.S. Department of Energy's Office of Nuclear Waste Isolation (ONWI) is the agency currently responsible for funding the project. Research is aimed at gathering and interpreting all geologic and hydrologic information necessary for describing and evaluating the salt bearing and related strata in the Palo-Duro Basin (Research Staff, 1981).

Waste Description

In order to put this paper into perspective, it is important to describe, first, the types of long-lived wastes created by the nuclear power cycle, and second, the periods of time important in their safe disposal. The three principal types of radioactive wastes considered appropriate for geological storage are high-level wastes from fuel reprocessing operations, "alpha-bearing" wastes, and encapsulated spent fuel elements, if declared as waste (Geologic Disposal of Radioactive Waste, 1984).

High-level wastes are defined in federal regulations as "those aqueous wastes resulting from the operation of the first cycle solvent extraction system, and the concentrated wastes from subsequent extraction cycles, in a facility for reprocessing irradiated reactor fuels" (Radioactive Waste Disposal, 1977). The principal radioactive constituents in these reprocessing wastes are the low volatility fission products (Table 1), small quantities of unextracted uranium and plutonium, and other transuranium elements such as neptunium, americium, and curium formed by transmutation of the uranium and plutonium in the reactors (Radioactive Waste Disposal, 1977). These wastes can be generally characterized by their very intense, penetrating radiation and their high heat generation rates. Regulations call for their solidification within 5 years after they are generated and for the resultant stable solids to be shipped to a federal

Table 1: Low-Volatility Fission Products

Cobalt - 60	Iodine - 129
Bromine - 84	Iodine - 131
Rubidium - 88	Te - 132
Rubidium - 89	Iodine - 132
Strontium - 89	Iodine - 133
Strontium - 90	Te - 134
Yittrium - 90	Cesium - 134
Yittrium - 91	Iodine - 134
Strontium - 92	Iodine - 135
Yittrium - 92	Cesium - 136
Zirconium - 95	Cesium - 137
Niobium - 95	Cesium - 138
Tc - 99	Ce - 144

Long-Lived Transuranics

Plutonium - 238	Americium - 241
Plutonium - 239	Americium - 243
Plutonium - 240	Neptunium - 237

The products of uranium fission and transuranic decay comprise a large number of elements and include both stable and radioactive isotopes of these elements. Among the more important radionuclides produced by uranium fissioning are isotopes of the alkali metals Cesium and Rubidium, the alkali earths Barium and Strontium, and the halogens Iodine and Bromine (low and high author, 1977).

repository within 10 years after the liquids are generated (Radioactive Waste Disposal, 1977).

Alpha-bearing wastes are defined as those solid materials that contain plutonium or other long-lived alpha emitting radionuclides in concentrations greater than 10 uCi/kg, and yet have sufficiently low external radiation levels that they can be handled directly without supplementary shielding. 10 uCi/kg corresponds to the uppermost range of alpha-emitting isotopes in naturally occurring deposits (Radioactive Waste Disposal, 1977). These wastes may include ion-exchange resins, fuel element hulls or components, and storage pond residues from reprocessing operations (Geologic Disposal of Radioactive Waste, 1984). Because this type of waste is in solid form and is produced in larger volumes, it must be compacted or incinerated before it can be immobilized in glass or plastic.

Spent nuclear fuel elements, if not reprocessed, pose a very different disposal problem. The presence of larger amounts of unextracted uranium and plutonium within the waste fuel assemblies cause them to be highly radioactive, and thus hotter, for much longer periods of time than high-level or alpha-emitting wastes. To be considered safe for geologic disposal, these fuel elements must be appropriately conditioned and packaged (Geologic Disposal of Radioactive Waste, 1984).

A perspective on the periods of time important in geologic disposal can be gained from a general knowledge of the rates of radioactive decay of the waste material. Many different species of radiotoxic nuclides are present within each class of waste, and each species has its own chemical timetable for radioactive decay. Most of the fission-produced radionuclides decay relatively rapidly from between 100 to 1000 years after generation (Geologic Disposal of Radioactive Waste, 1984). This is illustrated in Table 2. Still, the potential hazard from these "shorter-lived" products spans a longer time period than we are presently able to store and monitor above-ground with confidence.

The radionuclides of major concern are those with long half-lives such as the isotopes of plutonium and americium, as well as the isotopes Np-237, I-129, Tc-99, and the daughter products of uranium (Geologic Disposal of Radioactive Waste, 1984). These are the long-lived wastes that remain radioactive for hundreds of thousands of years and are the driving force behind developing a repository capable of isolating them for their long life span.

Geohydrologic Criteria

An acceptable high-level radioactive waste repository would be a facility that is located, designed, constructed, operated, and tested in such a way that society would be reasonably assured that the potentially hazardous radionuclides sealed in the repository will not enter the biosphere in harmful amounts or levels (Geologic Criteria for Repositories, 1978). Because movement by groundwater is the most probable means by which radionuclides might escape to the biosphere, the geohydrologic factors of the repository are among the most critical in choosing the site

Table 2: Evolution of the Radioactivity in Spent Fuel and High-Level Wastes Per Metric Ton of Heavy Metal in the Original Fuel Element

Time from reactor discharge years	Actinides and daughters in spent fuel	Actinides and daughters in high-level waste	Fission products in spent fuel or in high-level wastes
10	2660	120	11500
100	234	32.7	1270
1,000	57	8.5	0.8
10,000	16.3	0.94	-
100,000	1.4	-	-
1,000,000	0.5	-	-

Data illustrated are for a light-water reactor with a fuel burn-up of 33 GW-day/Ton and subsequent reprocessing <u>after</u> 5 years.

(Geologic Criteria for Repositories, 1978). Information from geologic and engineering studies, as well as hydrologic evolua- tion, must be taken into account to determine whether or not a site is acceptable for repository construction. In general, the hydrologic criteria employed are as follows:

I. Hydrologic analysis must define the local and regional groundwater flow regimes, and determine the effects of repository construction on those systems.

and

II. Analysis of the geologic record and previous hydrological conditions of the selected site for prediction of favorable or unfavorable long-term hydrological conditions.

The ultimate goal of these evaluating criteria is to define the hydrogeological properties of the chosen site (Geologic Criteria for Repositories, 1978). Although geologically dissimilar, each proposed U.S. waste disposal site will use similar criteria for repository emplacement

General Basin History and Host Unit Description

The Palo-Duro Basin (Fig. 1 and 2) is one of several basins that developed over at least 700,000 km^2 of the interior

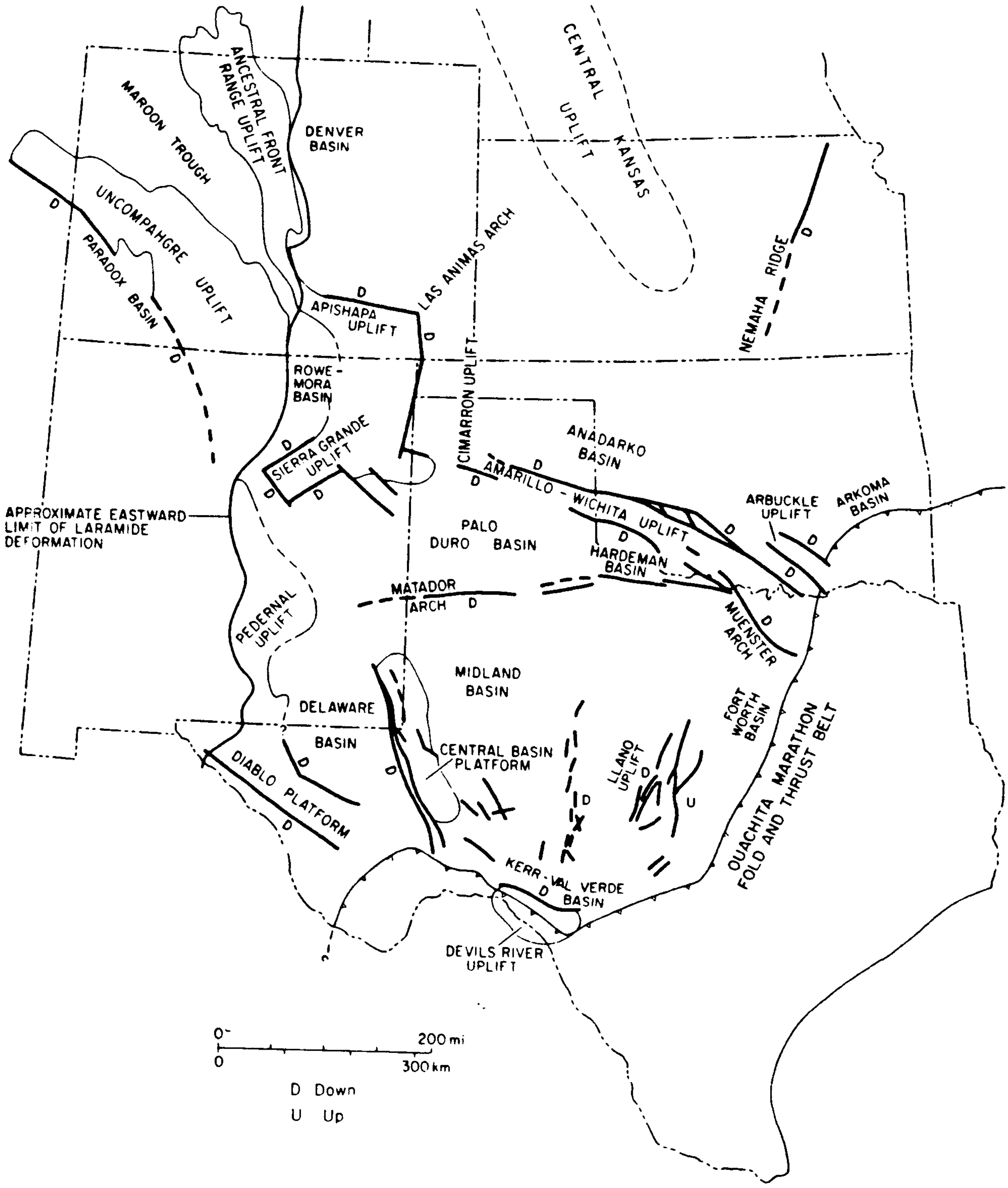

Figure 1: Map of Late Paleozoic structural elements showing the Laramide Front, Ancestral Rockies Uplift, and Palo-Duro Basin (Goldstein, 1982).

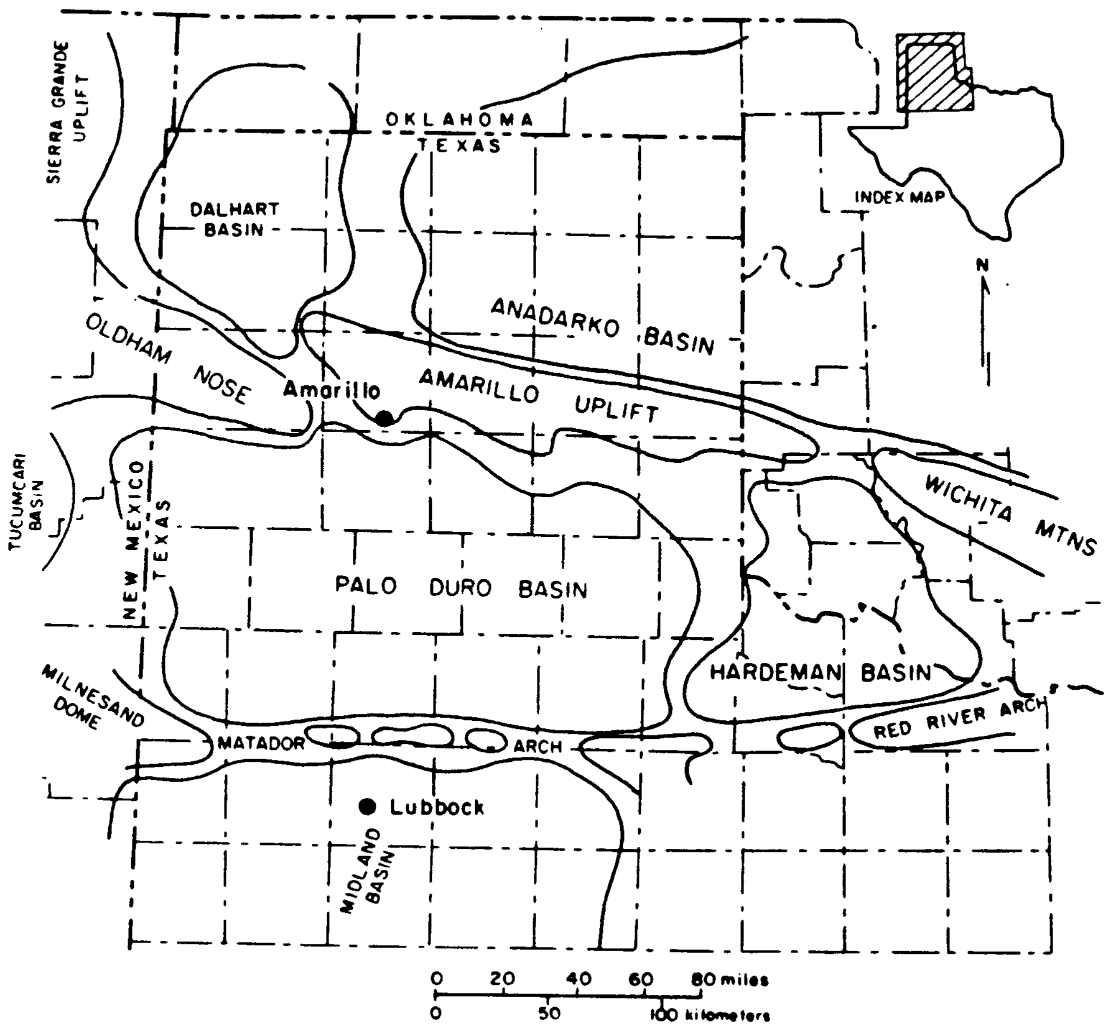

Figure 2: Structural elements of Texas Panhandle and location of Palo Duro Basin (Budnik and Smith, 1982).

province of the North American plate late in the Paleozoic Era. The basins are bounded by blocks of crust that were uplifted, forming a series of mountain ranges (some of which are called the Ancestral Rockies). The region as a whole underwent a period of subsidence in the late Pennsylvanian and Permian that eventually buried the uplifted basinal areas under marine and terrestrial clastic sediments (Goldstein, 1982). Within the Palo-Duro, especially along its northwest margin, movement along faults has affected the distribution of lithofacies, variation in thickness of sedimentary units, and, post-depositional deformation of strata (Research Staff, 1983). It was during this period of subsidence that the bedded salts of the Clear Fork Group, and the San Andreas Formation (Fig. 3) accumulated in extensive, flat-lying sabka environments (Fig. 4). The purity and thickness of these salt deposits was controlled mainly by differences in paleotopography, subsidence, and proximity to clastic sources during deposition. The purest salts (salt vs. mud content) will be found in areas that were both rapidly subsiding and remote from clastic input. A north-south cross-section through the basin (Fig. 5) illustrates how subsidence and continuous faulting controlled the distribution and thickness of stratigraphic units (McGookey and Goldstein, 1982).

Both the Clear Fork Group and the San Andreas Formation have been studied extensively as possible repository host units. They are characterized by cyclic, transgressional-regressional deposition of clastic and evaporitic sediments, with an overall increase in evaporitic salt thickness stratigraphically upward

SYSTEM	SERIES	GROUP	Palo Duro Basin FORMATION	Dalhart Basin FORMATION	General Lithology and depositional setting
QUATERNARY	HOLOCENE		alluvium, dune sand Playa	alluvium, dune sand Playa	
	PLEISTOCENE		Tahoka "cover sands" Tule / "Playa" Blanco	"cover sands" "Playa"	Lacustrine clastics and windblown deposits
TERTIARY	NEOGENE		Ogallala	Ogallala	Fluvial and lacustrine clastics
CRETACEOUS			undifferentiated	undifferentiated	Marine shales and limestone
TRIASSIC		DOCKUM			Fluvial-deltaic and lacustrine clastics
PERMIAN	OCHOA		Dewey Lake	Dewey Lake	Sabkha salt, anhydrite, red beds, and peritidal dolomite
			Alibates	Alibates	
	GUADALUPE	ARTESIA	Salado/Tansill	Artesia Group undifferentiated	
			Yates		
			Seven Rivers		
			Queen/Grayburg		
			San Andres	Blaine	
	LEONARD	CLEAR FORK	Glorieta	Glorieta	
			Upper Clear Fork	Clear Fork	
			Tubb	undifferentiated Tubb-Wichita Red Beds	
			Lower Clear Fork		
			Red Cave		
		WICHITA			
	WOLFCAMP				
?			?	?	
PENNSYLVANIAN	VIRGIL	CISCO			Shelf and shelf-margin carbonate, basinal shale, and deltaic sandstone
	MISSOURI	CANYON			
	DES MOINES	STRAWN			
	ATOKA	BEND			
	MORROW				
MISSISSIPPIAN	CHESTER				Shelf carbonate and chert
	MERAMEC				
	OSAGE				
ORDOVICIAN		ELLENBURGER			Shelf dolo[illegible]

Figure 3: Stratigraphic column and general lithology of the Palo-Duro Basin (Budnik and Smith, 1982).

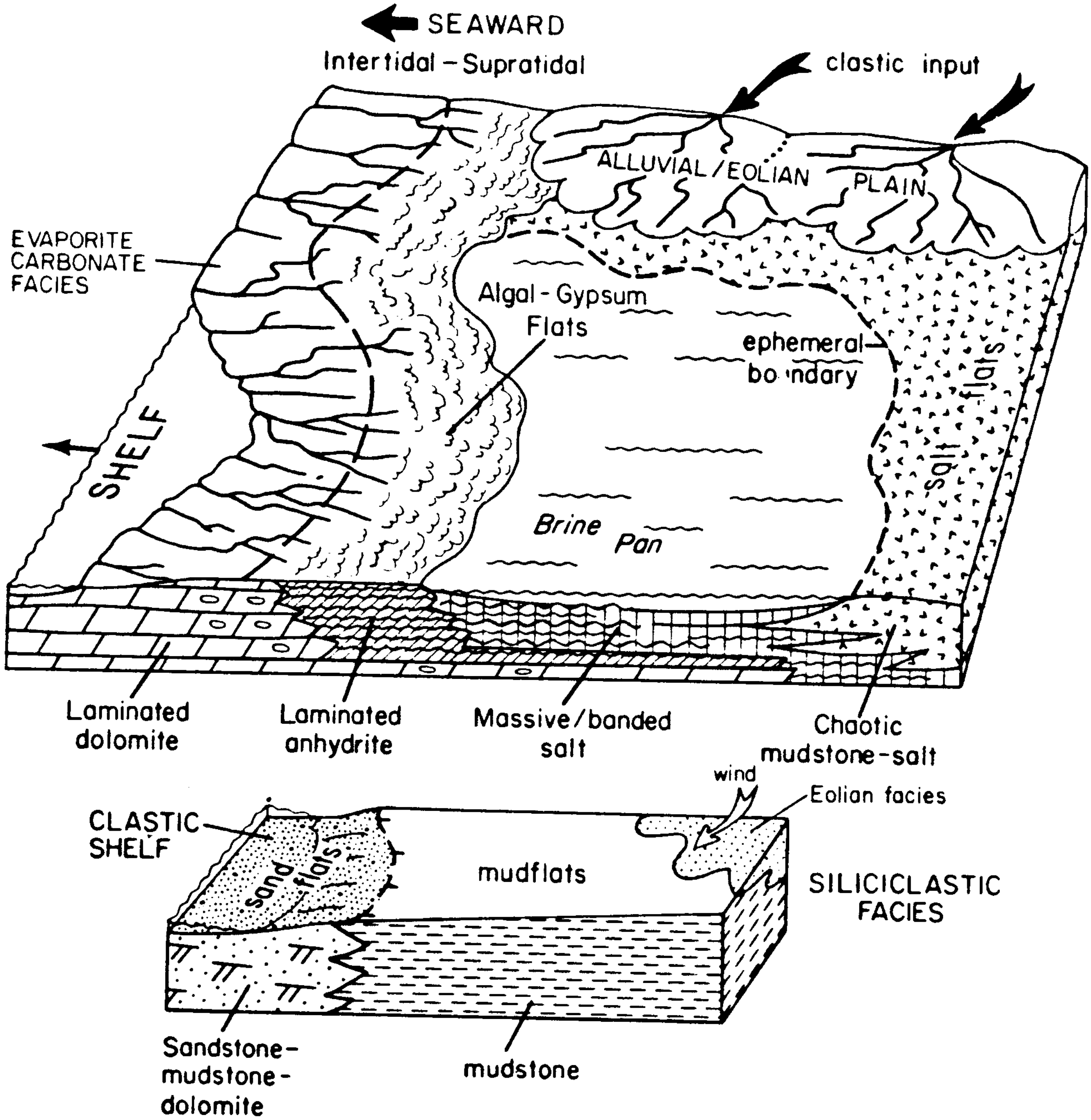

Figure 4: General evaporite-carbonate-clastic facies and environments of the Palo-Duro Basin (Budnik and Smith, 1982).

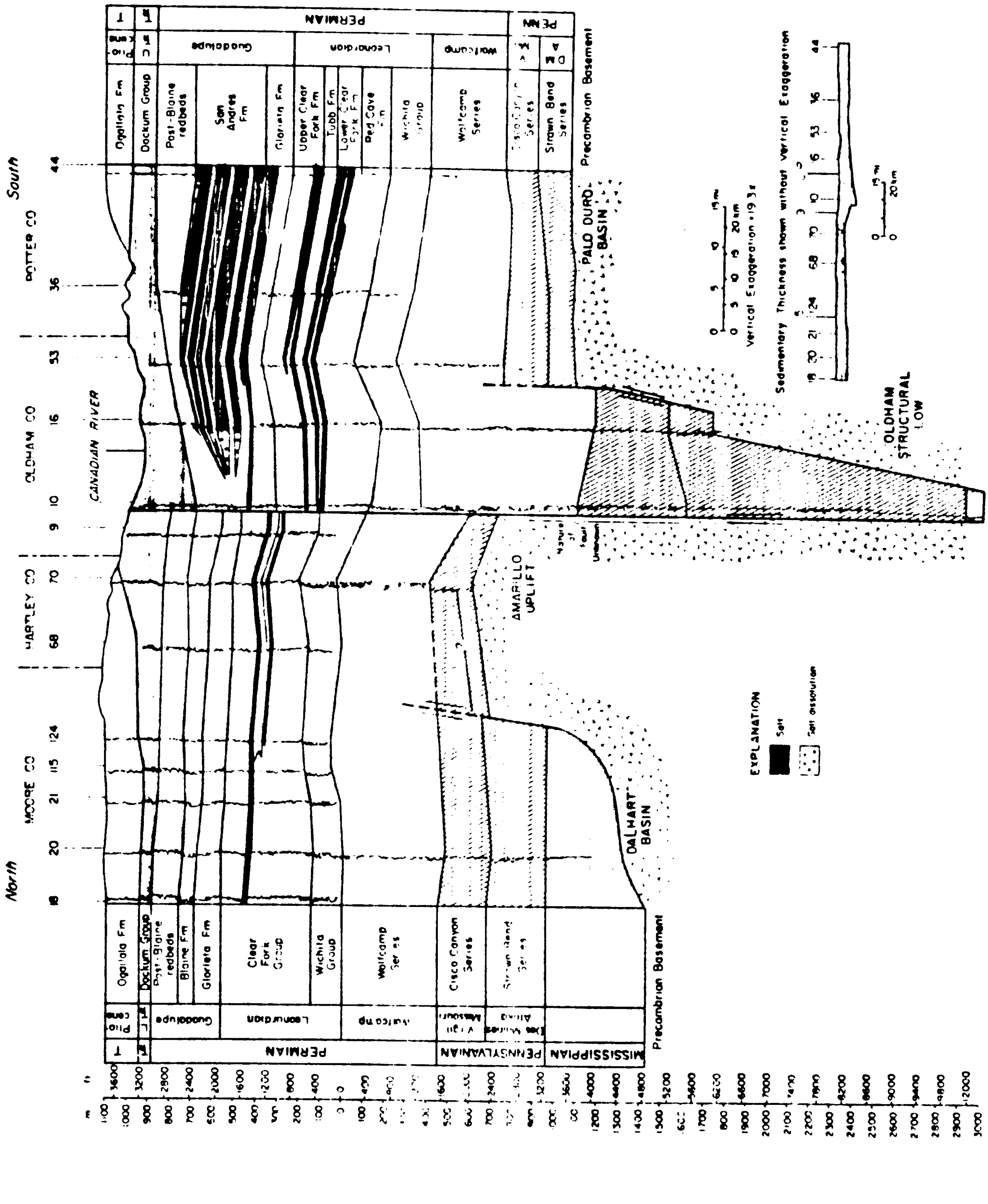

Figure 5: North-South cross section showing present configuration of strata across the Amarillo Uplift. For line of section, see Figure 2 (McGookey Goldstein, 1982).

(Budnik and Smith, 1982). Within the Clear Fork Group, the Upper and Lower Clear Fork Formations and the Tubb Formation contain salt deposits, however only the Lower Clear Fork contains beds theoretically thick enough (approximately 50 ft. thick) for repository construction. The San Andreas contains the thickest and purest salt sequences of the Basin. Bed thicknesses range from 45 to 200 ft. thick in the northern portion of the Palo-Duro (Presley, 1979).

Evaluation of Hydrologic Criteria

I. Hydrologic analysis must define the local and regional groundwater flow regimes, and determine the effects of repository construction on these systems.

Hydrologic analysis of local and regional groundwater systems associated with a particular repository site is crucial in characterizing the hydrologic performance of that site. As is the case for the Palo-Duro Basin, definition of groundwater systems must take into account the hydrologic properties of the entire geologic system, including its perturbation by the construction and presence of the repository, the specific geologic materials present, and the chemical and physical properties of the transporting fluids within the system. The specific hydrologic parameters are the dispersivity and the groundwater flow rates. Flow rate is largely determined by factors such as porosity, permeability, fractures, and hydraulic heads and gradients in the geologic environment (Geologic Disposal of Radioactive Waste, 1984).

The ideal repository host rock would have abnormally low hydraulic gradients and permeabilities, both within the actual unit, and within units stratigraphically above and below. Groundwater flow rates, locally and over a more extended regional area, would be characterized as infinitely slow. This ideal host rock would also show a high degree of homogeneity and be uncompromised by fracturing, jointing, or dissolution of rock material.

Within the 10,000 to 11,000 ft. sedimentary sequence of the Palo-Duro, some of these ideal host rock properties are not met. The Permian salt-bearing sequence is immediately underlain by a Wolfcampian carbonate aquifer. Average permeabilities within this brine aquifer range from 1 to 10 md, as estimated from drill-stem-test charts, and regional hydraulic gradients across the basin indicate a general, eastward fluid migration. The evaporite section above acts as a low permeability barrier above the transmissive carbonate (Bassett and Bentley, 1983). Dissolution rates along this boundary may be high, though, because the brines tend to be in equilibrium with the carbonate rocks, but not in equilibrium with the overlying evaporites (Bassett and Bentley, 1983).

The Triassic and Tertiary rock units directly above the Permian beds are the Dockum and Ogallala Formations respectively. These units are used as freshwater aquifers throughout the Western and Midwestern United States. Regional computer modeling across the Palo-Duro, using average permeability values of major hydrologic units, indicate two separate flow regimes: 1) a shallow flow system, consisting of the Ogallala and Dockum Fms., which is governed primarily by topography and 2) the deeper carbonate-brine aquifer regime recharging in New Mexico and passing beneath the Permian evaporites (Fig. 6 and 7). On the basis of this modeling, groundwater travel times across the basin may be as long as 45 million years within the deep aquifer. Residence times within the evaporites are probably similar to those of the carbonates below (Senger and Graham, 1983).

Joint density is an important factor for evaluating a nuclear waste repository site. Joints affect the ability of rock to transmit and hold fluids and also influence rock strength. Systematic joints measured in Permian rocks of the Palo-Duro that are exposed in Briscoe County, display a variety of orientations and densities (Fig. 8). The time of jointing is unknown, having formed as a result of stress systems that occurred syndepositionally and during subsidence or uplift. Joint zones are narrow belts or trends within a unit in which the joint density is greater than the predominent joint density of that unit. The joints within the Briscoe County area extend vertically through the Permian and Triassic beds, but do not cut through the Tertiary units. This indicates they formed before Tertiary sedimentation, and have remained stable since that time. The joint zones, much like the faults within the basin, act as groundwater pathways, and can greatly influence dissolution of the Permian salt

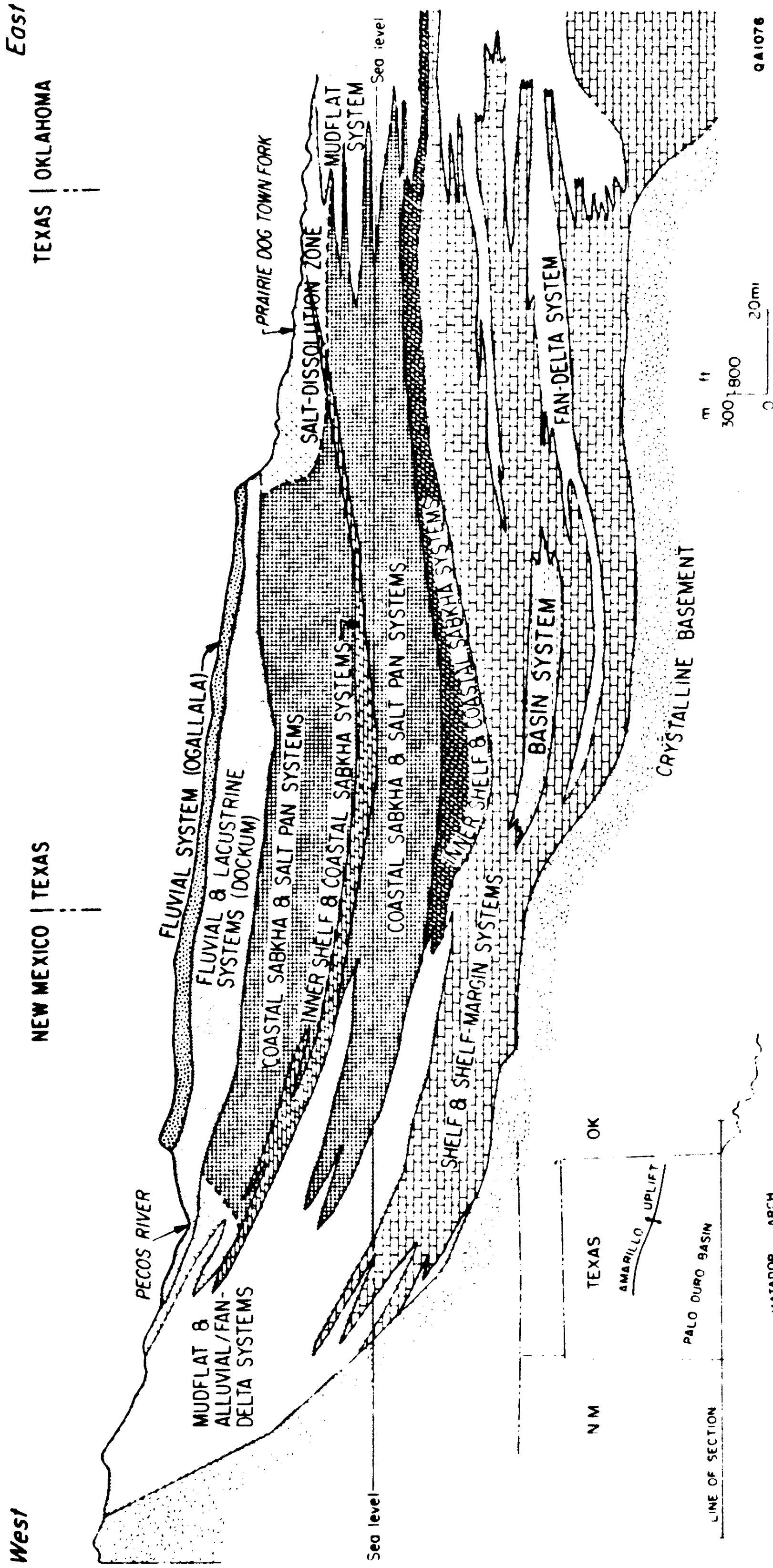

Figure 6: Regional east-west cross section through eastern New Mexico and the Texas Panhandle illustrates relation of major depositional systems (Senger and Graham, 1983).

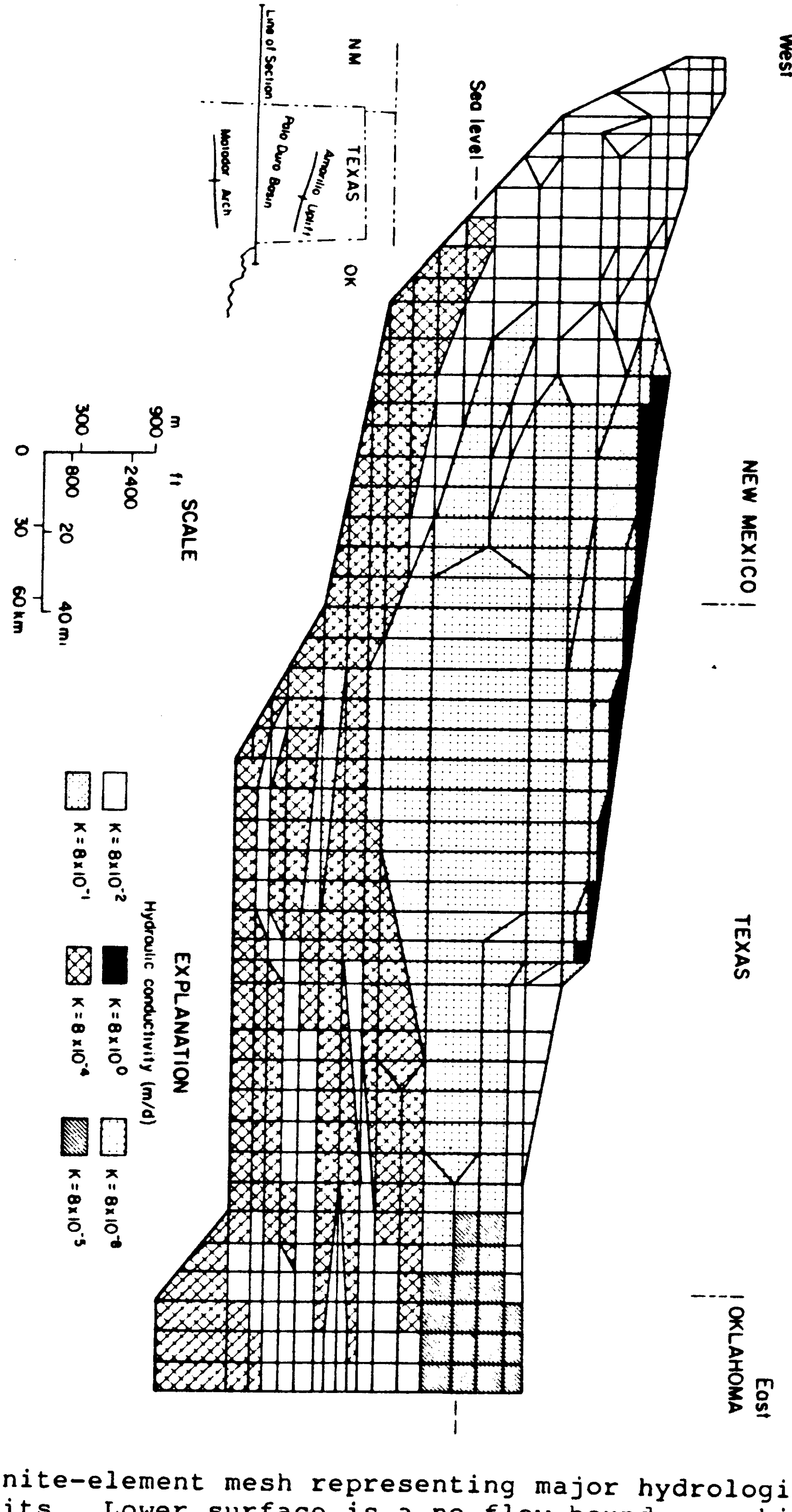

Figure 7: Finite-element mesh representing major hydrologic units. Lower surface is a no-flow boundary, which corresponds to contact between Paleozoic aquifers and basement rocks (Senger and Graham, 1983).

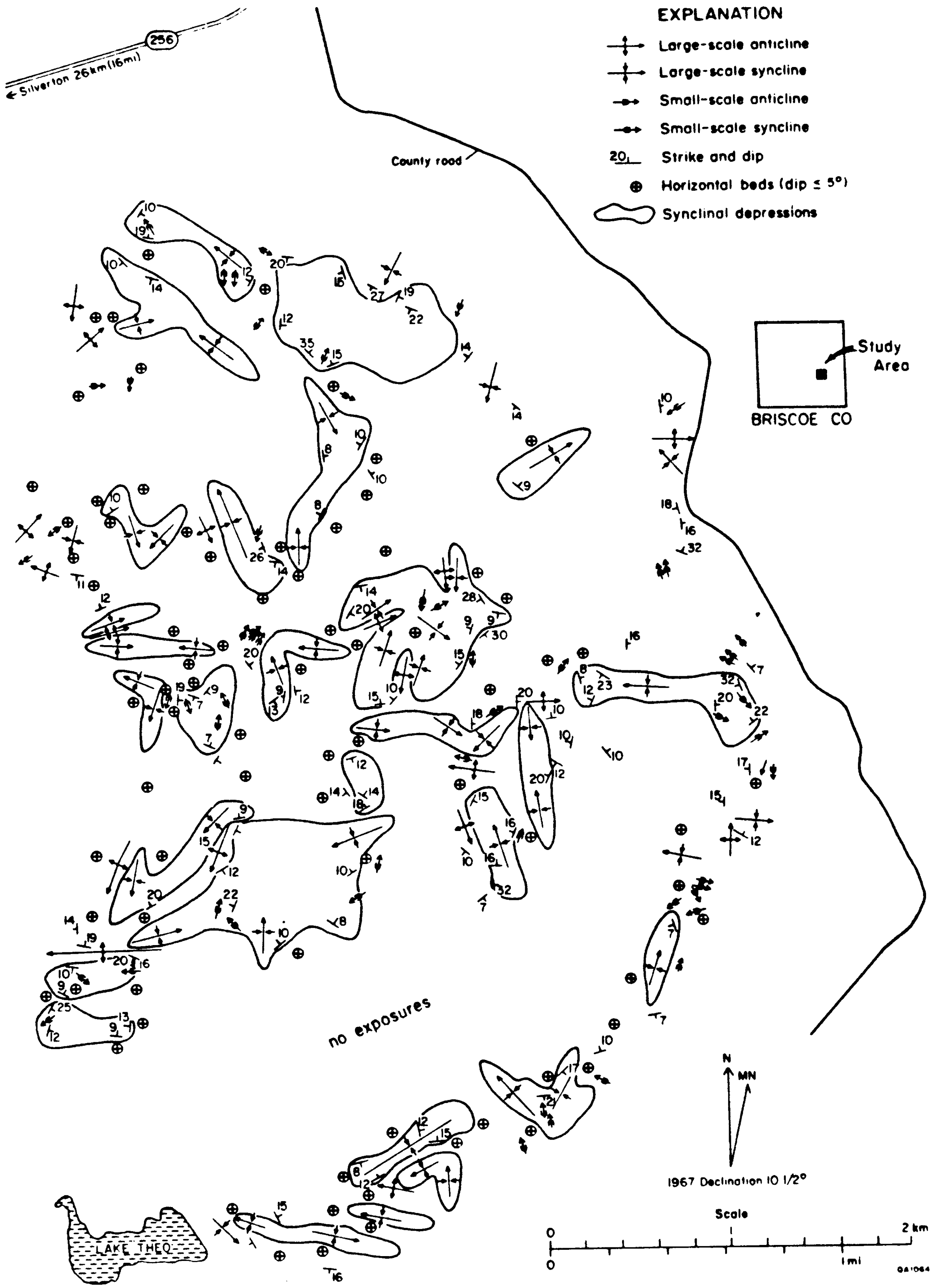

Figure 8: Structure map exhibiting variable geometry of folding in Briscoe County (Collins, 1983).

beds (Collins, 1983). Site specific joint survey and mapping studies must be made for any proposed repository site.

II. Analysis of the geologic record and previous hydrological conditions of the selected site must be made for prediction of favorable or unfavorable long-term conditions.

Regional analysis of the geologic record and of previous hydrological conditions of the repository site must be made in order to carefully consider probable future hydrological conditions. Long-term climatic predictions are uncertain, especially in view of the ever increasing significance of human activity, and overall trends can be modeled in only the most general terms (Geologic Disposal of Radioactive Waste, 1984).

It must be accepted that at some point in the geologic future, many of the factors that constitute the hydrologic performance of a repository site are going to change. This may be due to climatic changes, activation of old or new tectonic systems, geomorphological changes, or perturbation by future generations.

The long-term stability of the Palo-Duro Basin is demonstrated by the fact that the Permian salt deposits have remained substantially unaltered and relatively free from major dissolution for nearly a hundred million years. This makes it very attractive as a potential repository host site (Geologic Disposal of Radioactive Waste, 1984). Nevertheless, salt dissolution is recognized both geologically and historically. Salt dissolution zones are recognized within the Palo-Duro by: 1) abrupt loss of salt sequences between closely-spaced wells and 2) abrupt thinning of stratigraphic sequences away from salt-bearing strata, suggesting dissolution rather than facies changes (Gustavson, Hoadly, and Simpkins, 1981). Karstic dissolution features are a recognized part of the Palo-Duro Basin's topography presently, and should be considered as an integral part of future landscape development.

Conclusions

Given the hydrologic data presented, it is theoretically feasible to safely construct a waste repository within the Permian San Andreas Formation; unfortunately, the long-term integrity of such a repository may not be possible to define.

At present ONWI is evaluating a specific site in Deaf Smith County on the west edge of the Texas Panhandle. This is a long awaited and much needed study development. The next logical step in the study will be the construction of a "model" repository within the area or a similar area. Until this has been done we will be unable to properly define the impact of construction and thus repository integrity within the Palo-Duro Basin.

Basset, R. L., and Bentley, M. E., 1983, Deep Brine Aquifers in the Palo Duro Basin: Regional Flow and Geochemical Constraints, The University of Texas at Austin Bureau of Economic Geology Report of Investigation No. 130, pp. 32-35.

Budnik, R. and Smith, D., 1982, Regional Stratigraphic Framework of the Texas Panhandle, the University of Texas at Austin Bureau of Economic Geology Geological Circular 82-7, pp. 38-86.

Collins, Edward W., 1983, Joint Density of Permian Strata at Coprock Canyons State Park, Briscoe County, Texas, The University of Texas at Austin Bureau of Economic Geology Geological Circular 83-4, pp. 36-39.

Geological Criteria for Repositories for High-Level Radioactive Wastes, 1978, Committee an Radioactive Wastes: The National Research Council, pp. 9-11.

Geologic Disposal of Radioactive Waste: An Overview of Current Understanding and Development, 1984, OECD Nuclear Energy Agency, pp. 13-29.

Gimera, Davis, 1982, in: The Treatment and Handling of Radioactive Wastes, Batelle Press, Blasewitz, Davis, and Smith (eds.), pg. 611.

Goldstein, A. G., 1982, Regional and Plate Tectonic Setting of the Palo Duro Basin, The University of Texas at Austin Bureau of Economic Geology Geological Circular 82-7, pp. 6-10.

Gustavson, T. C., Hoadley, A. D., and Simpkins, W. W., 1981, Salt Dissolution and Collapse Along the Margin of the Southern

High Plains, The University of Texas at Austin, Bureau of Economic Geology Geological Circular 81-3, pp. 130-145.

McGookey, D. A. and Goldstein, A. G., 1982, Structural Influence on Deposition and Deformation at the Northwest Margin of the Palo Duro Basin, The University of Texas at Austin Bureau of Economic Geology Geological Circular 82-7, pp. 28-37.

Presley, Mark W., 1979, Salt Deposits, The University of Texas at Austin Bureau of Economic Geology Geological Circular 79-1, pp. 50-56.

Radioactive Waste Disposal, Low and High Level, 1977, Pollution Technology Review No. 28, Noyes Data Corporation, Gilmore William R. (eds.), pp. 9-45.

Research Staff, 1981, Palo Duro and Dalhart Basin Studies--A Summary of Third-Year Research, The University of Texas at Austin Bureau of Economic Geology Geological Circular 81-3, pp. 3-5.

Research Staff, 1982, Palo Duro and Dalhart Basin Studies--A Summary of Fourth-Year Research Activities, The University of Texas at Austin Bureau of Economic Geology Geological Circular 82-7, pp. 3-5.

Research Staff, 1983, Palo Duro Basin Studies--A Summary of Fifth-Year Research Activities, The University of Texas at Austin Bureau of Economic Geology Geological Circular 83-4, pp. 3-5.

Senger, R. K., and Graham, E. F., 1983, Regional Modeling of Ground-Water Flow in the Palo Duro Basin, Texas Panhandle, The University of Texas at Austin Bureau of Economic Geology Geological Circular 83-4, pp. 109-115.

Smith, D. Anderson, Bassett, Randy L., and Roberts, Michael P., 1983, Potentiometric Surface of the Wolfcampian Aquifer, Palo Duro Basin, The University of Texas at Austin Bureau of Economic Geology Geological Circular 83-4, pp. 94-96.

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